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MINE4122:

MINING RESEARCH PROJECT II

GEOTECHNICAL ANALYSIS OF THE STABILITY OF A 70 DEGREE HIGHWALL VS 45 DEGREE SOFTWALL

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SUMMARY

Through researching current literature on highwall and softwall designs as well as their, risks and benefits, major gaps were found in relation to softwalls. Softwalls are generally implemented due to a common and logical engineering assumption that if the angle of a slope is reduced, the stability is increased. However, when applying this into mining situations, it impacts the productivity and in turn, the costs of the mine. Thus, it was deemed worthy of a study to quantify the safety improvements as well as the changes in productivity and costs.

Meandu Mine, an open cut coal mine in the Tarong Basin who currently implement a softwall design which allowed for quantitative results to be compiled. Currently, no quantitative analysis has been completed on the benefits or disadvantages, making this study beneficial specifically to the site. The softwall is currently implemented in the Central Pit only, resulting in all analysis being completed for this pit specifically.

By analysing how the geological model is generated, it's accuracy was determined and found that the model was highly accurate due to the use of extensive boreholes. However, due to the erratic nature of the faults and geology at Meandu, discrepancies between the model predictions and actual locations of the coal seams and faults occur. From this, a flexibility zone was determined around both the coal seams and the faults to highlight the area in which they were likely to fall. A zone ±1.5m around the seams highlighted the area in which the seam was likely to fall 95% of the time. Similarly, a ±15m zone around faults was determined. The increase in size of the faults was due to the large throw and irregular nature of the them.

The materials present in Central Pit were then examined to determine their strength parameters. As no samples were able to be gathered, previously gathered data was used. Due to the lack of data in Central Pit, extrapolation of the data was completed. Extrapolation was completed based on the material type and the coal horizon. This allowed the differences between the different interburdens to be observed. By then averaging the data to the different material types, it was found that the majority of materials present in Central Pit are quite weak. In addition to their weakness, a number of the observed material properties emphasised their susceptibility to fail. Laminations were common as well as high friability which saw failure possible during excavation.

Using these material properties, the risks and benefits of highwalls and softwalls were examined. It was determined that due to the jointing and properties of the material, wedge and slump failure were of greatest concerns. Additionally, the risks of rock fall and material movement due to blasting were also considered as they are common risks associated with highwalls. It was seen that the risks of wedge and slump failure, as well as rock fall, all reduced when a softwall was implemented. However, due to the nature of a softwall, the risk of movement due to blasting increased. Even with the increase in risk, it was deemed safe and manageable with continual monitoring. This continual monitoring has been implemented along the softwall at Meandu.

To complete the measureable analysis, a productivity and cost investigation was completed. Due to the nature of Central Pit, production occurs via dragline. Productivity was found to decrease as a 274% increase in material movement was observed with the implementation of a softwall. In addition to this increase in productivity, an increase in rehandle was also observed. Due to Central Pit being a constricted area, the dragline spoil piles are required to be stacked higher and further away to ensure a suitable work area. From this, the production hours increased from 30 hours for a highwall to 90 hours for a softwall. This increase in material and hours resulted in an increase in costs. Due to confidentiality reasons, actual costs were withheld from the report, however, indicative costs saw an increase of 312%. This increase however did not include the cost of drill and blast. It was deemed that no accurate modelling of the drill and blast costs could be completed. This was because Central Pit is mined via strip mining with continual changes in material, the drill and blast requirements alter with each strip.

It is recommended that even with such an increase in required time and costs for a softwall, due to the nature of Central Pit, it is to be maintained. The use of a softwall increases the safety and stability of the wall, ensuring a safe working environment. Investigation into other mitigation options resulted in these options being highly time consuming and labour intensive. Additionally, it is suggested that soil samples be gathered from Central Pit and be tested to gather qualitative strength properties. These results can then be used to model the slope to find an optimal angle for the softwall. By obtaining an optimal angle, productivity can be maximised while minimising costs.

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1. INTRODUCTION

1.1 BACKGROUND

Meandu Mine is an open cut coal mine located in the South Burnett region of Queensland. Coal was discovered in 1939 during the development of roadways but, a lack of a coal market in the area at the time, meant that mining did not commence until 1978 (Huleatt, 1991). The mine was started in 1978 by Rio Tinto Coal as the sole provider to the Tarong Power Station. In 2008, the mine was sold to Tarong Energy then again in 2011 to Stanwell. After purchasing the mine, Stanwell employed Downer Mining as contractors (Stanwell, 2014).

The geology of the mine is complex and contains many faults which generates many issues when mining. The current highwall practice at the Meandu is to have 70° inter-ramp angles, with benches every 10m. However, in some areas, maintaining a 70° highwall can be deemed as unsafe due to faults, weak material and other geological reasoning. In these situations, a 45° softwall is implemented. A softwall, is wall containing no benches and with highly blasted material (Kelso, 2011). A comparison of a standard highwall design and a softwall is illustrated in Figure 1.

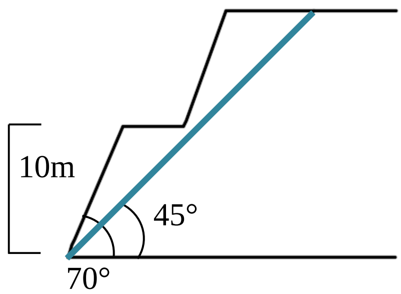


Figure 1. Standard Highwall and Softwall Design at Meandu Mine

It is known that when a softwall is implemented, a decrease in productivity is incurred due to the extra waste that is required to be moved. However, there has been no quantifiable assessment to analyse the impact of productivity and the reduction in geotechnical risk. This project aims to provide a quantitative comparison of the data for Central Pit at Meandu Mine.

1.2 PROJECT AIMS

The aim of this project was to provide a quantifiable comparison between the standard highwall and softwall designs at Meandu Mine, specifically for the Central Pit. This allowed for further investigations into other mitigation options to observe if there could were better suited methods. To complete this aim, a number of objectives were accomplished which included;

- Identifying areas within the Central Pit where the use of a softwall is required;
- Examining materials present in this area and their stability properties;
- Analysing the accuracy of the geological model;
- Identifying the risks if a softwall was not implemented;
- Quantifying the reduction in risk due to the softwall implementation; and
- Completing a cost analysis.

1.3 PROJECT SCOPE

To ensure the comparison was accurate and thorough, the analysis was conducted solely for Central Pit. The quantitative results will allow Meandu to determine if softwall implementation is the best mitigation technique. The following points were addressed in completing the analysis of the softwall;

- Identification of possible failure mechanisms;
- Assessment of geotechnical risks;
- Examination of equipment productivity and usage;
- Material movement and rehandle alterations; and
- Financial assessment of both highwall and softwall development.

While there have been no formal investigations into other mitigating options, it was deemed in scope for this project to detail their applicability for Central Pit at Meandu. Furthermore, it was assumed that the required social and environmental legislations have been adhered to thus, all designs are deemed to conform to regulation. Additionally, while the stress orientation and magnitudes are important for mine design, they were not considered in this analysis as they generally do not impact on shallow excavations. This project examined the faults, changes in strata and material characteristics under the assumption that field stresses do not impact the design or implementation of the walls. Finally, the analysis of the current geological model was conducted to identify accuracy of the data input into the model. However, the generation of a new model was deemed out of scope thus, the model generated by Downer Mining and Stanwell was used for the completion of this project, irrespective of the outcomes of the analysis.

1.4 INDUSTRY RELEVANCE

Conclusions drawn from this research paper can be applied directly to Meandu to generate maximum stability and safety in Central Pit and potentially other pits at Meandu. Furthermore, it was aimed that this paper offered quantitative comparisons on costs, geotechnical risks and material handling between the two designs. While the results will solely relate to Central Pit, the process and analysis techniques could be applied to other pits and sites to analyse the current design standards. Overall, if the projected outcomes are achieved within this paper, there is an opportunity to quantify a productivity and safety analysis of highwall and softwall designs at Meandu and project this to other sites.

1.5 METHODOLOGY

For the aims and objectives of this project to be met, a methodology was generated to ensure accurate and meaningful results were obtained. By completing an analysis of the geology of Meandu Mine and a literature review of highwall and softwall designs, a thorough understanding of the background to the area and problem was established. Furthermore, problematic areas were identified within Central Pit at Meandu followed by an analysis of the geological model.

From this, an analysis of the different materials and their stability was completed, followed by an investigation into the risks associated with highwalls and softwalls. Finally, a productivity and financial comparison was completed to determine the overall mining effects. The completion of this methodology allowed for a detailed and complete examination to take place and result in detailed quantitative results.

2. LITERATURE REVIEW

The completion of a literature review allowed for a thorough understanding of current highwall and softwall practices to be gained. A review of open pit mining limitations and hazards identified common problems associated with the mining practice. From this, possible failure mechanisms of highwalls and their impacts on mining were recognized. However, literature on the stability and design of softwalls was limited due minimal research and implementations. As a result, case studies were analysed to classify softwall mechanisms as well as identify situations when softwalls have aided in the mitigation of failures.

2.1 OPEN PIT MINING

Open pit mining is the process of extracting ore by removing the waste material which covers the deposit. Open pit mining is ideal for shallow deposits with a generally low dip angle (Brawner and Milligan, 1971). Open pit mining has many advantages including; simple development and access requirements, high production rates and it is relatively flexible (Davidson, 1986). However, there are also some disadvantages and limitations to this process as well including;

- Limitations in the depths economically achievable;
- Extensive environmental concerns;
- Delays and impacts due to weather; and
- Slope stability requirements (Brawner and Milligan, 1971).

Furthermore, there are hazards specifically related to coal mining include;

- Acid mine drainage;
- Coal fires; and
- Health implications (Department of Justice, 2013).

As it can be seen, there are a number of limitations and hazards associated with open cut coal mining however, only the analysis of slope stability is deemed relevant to this topic. Although, it is important to be aware of the other limitations and risks associated with this mining method as they affect many parameters associated to the mine design.

2.2 HIGHWALLS

2.2.1 Design

Highwall design is an integral part of mine design and is an important factor in determining ore recovery and safety measures. Ensuring the stability and safety of highwalls should be one of the highest priorities to engineers for if the stability and safety of a highwall is compromised, the safety of all workers is also compromised (Grenon and Hadjigeorgiou, 2007).

General designs of highwalls are consistent amongst a majority of open cut coal mines (Grenon and Hadjigeorgiou, 2007). However, there are specific parameters of the design which are determined by the geology, geotechnical conditions and equipment selection. These parameters include;

- Inter-ramp angle;
- Overall slope angle;
- Bench height;
- Haul road width; and
- Bench width (Bye & Bell, 2001).

These parameters are determined by material strength and stability as well as specific equipment requirements. Furthermore, coal seam shape, width and orientation also influence the optimum value of these parameters.

2.2.2 Stability

Piteau (1972) determined that the stability of slopes was characterised more by the discontinuities present in the rockmass than the strength of the rockmass itself. The understanding of the possible failure mechanisms is important to ensure that if failures start to generate after excavation, precautionary measures are in place. It is ideal that the pit be designed in a manner to reduce the likelihood of failure occurring such as, orientating the pit to allow for the bedding to dip outward (Bye & Bell, 2001). At Meandu, this was aimed to be done for a number of pits however, as faults and their extents were discovered, it was found that a favourable orientation for one fault was unfavourable for another.

2.2.2.1 Plane Failure

Plane failure is an event in which discontinuities present within the rockmass form a block or wedge and a face on which they can slide. Generally, the discontinuities are bedding planes, faults or joints within the rockmass (Wyllie & Mah 2004). For plane failure to occur within a slope, there are a number of geometric conditions which need to be met. Firstly, the failure plane, the plane on which the rockmass slides, must be within 20^{O} of parallel to the slope face (Wyllie & Mah 2004). Furthermore, the dip of failure plane must be less than the slope angle, yet larger than the angle of friction of the material. Additionally, the rockmass on the sliding surface must culminate at a tension crack or intersect at the surface (Wyllie & Mah 2004). This defines the body of the failure and a schematic of planar failure is illustrated in Figure 2. Due to the complexity of the required geometric criteria of plane failure, it is a rare occurrence.

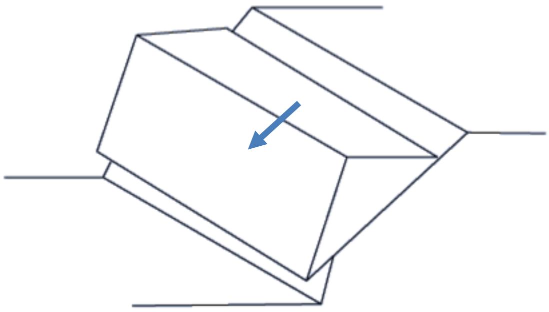


Figure 2. Planar Failure (Wyllie & Mah 2004)

If an insufficient geotechnical analysis is completed prior to development, the risk of plane failure increases. This emphasises the importance of completing thorough geotechnical investigations to ensure the pit is orientated to best accommodate faults and geological phenomena (Davidson, 1986). While planar failure was not seen as a high rick potential failure method for Central Pit it deemed necessary to investigate all failure methods to observe a thorough understanding of slope stability.

2.2.2.2 Wedge Failure

Wedge failure occurs when two defined planes intersect at an oblique angle, resulting in a wedge forming which has the potentially to slip down the plane faces (Kumsar, Aydan & Ulusay, 2000), as shown in Figure 3. For the failure to occur, the intersection of the failure planes needs to daylight (Grenon and Hadjigeorgiou, 2007). When excavating in mines, it is possible to expose these intersections which will generate failure. While sampling and testing may conclude the materials present are stable and strong, disturbing the in-situ properties may destabilise the material (Wyllie & Mah 2004).

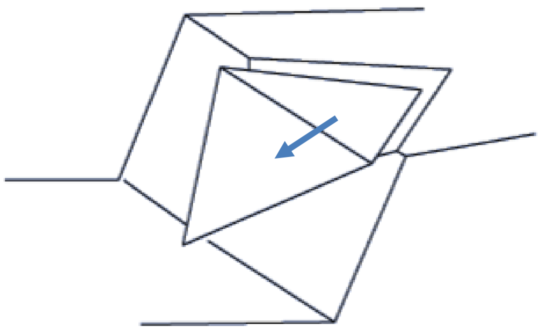


Figure 3. Wedge Failure (Grenon and Hadjigeorgiou, 2007)

Wedge failure can be hard to recognise when excavating slopes as the likelihood of wedge failure occurring has traditionally been determined by the factor of safety (Leroueil, 2001). Thus, it is the ratio between forces aiding and resisting the failure that determine the failure point (Leroueil, 2001). It was determined that wedge failure was applicable to Central Pit due to the faulting and discontinuities. Additionally, as the pit implements both a 70 degree and 45 degree wall next to each other, the change in angle can result in wedge failure. Thus, understanding the mechanisms of wedge failure is an important aspect to this study.

2.2.2.3 Toppling Failure

Toppling failure can occur via two mechanisms; direct and flexural. Direct toppling occurs when the centre of gravity lies outside the base of the block outline resulting is continual toppling of the effected sections (Wyllie and Mah, 2004). Furthermore, it does not use the strength parameters of the rockmass in the kinematic criteria however, only applies the geometry of the rockmass (Hudson and Harrison, 2000).

In comparison, flexural toppling occurs when bending occurs in steeply dipping discontinuities of an interacting rock column (Adhikary et al., 1997). For these failures to occur, steeply dipping parallel discontinuities are required which creates planes for the material to bend on (Amini, Majdi and Aydan, 2008). Toppling failure is not expected to occur at Meandu Mine as the geology and geotechnical conditions do not align with the requirements.

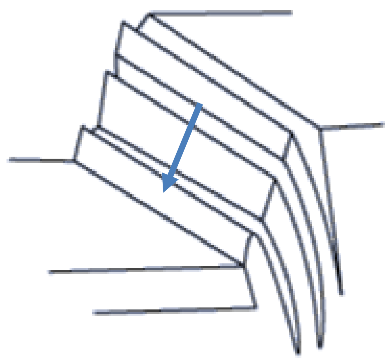


Figure 4. Flexural Toppling Failure (Adhikary et al., 1997)

Similarly, to planar failure, toppling failure is not considered as a likely mode of failure at Meandu yet, deemed important in understanding the fundamentals of the project.

2.2.2.4 Slump Failure

Slump failure occurs when material moves along a concaved slip surface as depicted in Figure 5. Slump failure generally occurs on unconsolidated regolith that has been saturated (Swanston, n.d.). Additionally, due to the curved nature of the slip surface, the slumped material usually rotates. Slumps are usually a result of heavy rainfall or excavation but can also be the result of a number of geological, morphological or human causes (U.S Geological Survey, 2004). If a slump failure was to occur at Meandu, it would be a result of excavation in association with the bedding and jointing of the materials. Slump failure is deemed a likely method of failure in Central Pit.

Figure 5. Slump Failure (Swanston, n.d.)

2.3 SOFTWALLS

2.3.1 Design

A softwall is a wall in which the *rock mass is blasted beyond the pit limit* (Kelso, 2011). This blasted material is then pushed to a shallower than usual slope angle to manage any potential failure (Kelso, 2011). Benches are not included in the design however, in conditional circumstances, catch benches can be implemented below the wall. However, due to the amount of extra material that is required to be moved as well as increases in blasting and possible rehandle, there is a higher associated cost to softwalls (Aksoy, 1994). The use of a softwall can aid in mitigating potential failures especially around large displacements that are resulted from faults (Simmons, 2012).

2.3.2 Stability

The stability of the softwall is developed by the consolidation of the material. As the material is blasted it no longer holds its in-situ strength and compaction (Kelso, 2011). This results in movement being the largest cause of failure in softwalls. As the wall is at lower angle than the angle of repose of the material, the material naturally maintains the slope (Kelso, 2011). However, as the material is loose, when large movements occur, such as blasting or seismic activity, movement in the wall is expected which has the possibility to result in failure. a softwall is implemented to reduce the potential and severity of failure occurring. However, failure will not occur through the same mechanisms as it does for a standard highwall (Thiess Burton Geotechnical Team, 2013).

Reynoldson (2015) discussed a mine inspection after failure occurred once the wall design was changed from a softwall to a 70° highwall. The implementation of the softwall increased the stability of the wall and allowed for excavation to continue. This lead to a geotechnical assessment being completed and the results indicated that a 70° highwall would sustain. This would also see productivity maximised (Reynoldson, 2015). A factor of safety for the highwall was derived to be 1.5-1.6 however, constant monitoring and constant inspections were suggested to be maintained. Substantial fracturing was observed after blasting occurred in close proximity to the wall as well as the possibility of wedge failure. From this, the pit was cleared of people and equipment before failure eventually occurred. Investigations found that had the softwall design been maintained, the prospect of failure would have been reduced (Reynoldson, 2015). This emphasises the effectiveness of softwall in reducing the probability of failures occurring.

Another case study completed at Thiess' Burton Mine identified that the implementation of a softwall, after a wedge failure, aided in the mitigation of the further failure (Thiess Burton Geotechnical Team, 2013). Major faults were known in the area and the possibility of wedge failure was identified and eventually failed on Australia Day 2013. After detailed assessment of the failure, it was identified that implementing a 50° softwall would reduce the probability of further failure occurring (Thiess Burton Geotechnical Team, 2013). While the angle of repose is not stated in the case study, it can be assumed that the softwall was implemented at an angle less than the angle of repose. This assumption is based on the fundamental theory of softwalls being most effective when angled lower than the angle of repose. Radar monitoring was implemented to monitor the movement of the softwall with controls associated to the different movements summarised in Table 1.

Table 1.
Fall of Ground Types, their Defining Areas and Key Controls

Fall of Ground Type	*Surface Area*	*Key Control*
Major	>5 pixels (>125m^2)	Safety critical slope (softwall)
Minor	>1 pixel, <5 pixels (25 to 125m^2)	Stability radar monitoring, Spotter
Rock fall	<1 pixel (<25m^2)	Physical barrier (catch trench or bund)

Source: Thiess Burton Geotechnical Team (2013)

The implementation of the softwall resulted in minor fails occurring which was significantly reduced to the failure experienced with the highwall. However, it was observed that some movement on the wall still occurred. It was emphasised in the case study that a softwall should never be implemented under the assumption of removing failures. The Thiess Burton Geotechnical Team (2013) acknowledged that a softwall only minimised the severity and possibility of failures.

2.3.3 Mechanisms

The mechanisms of softwalls has not been thoroughly investigated as it believed to be a common engineering assumption to lower the angle of a slope to increase its stability. By reducing the angle at which a slope sits, it reduces the weight of the area tending to slide or fail. As this weight is reduced the force motivating the failure is reduced. Furthermore, the reduce angle, reduces potential of discontinuities to daylight (Kelso, 2011). This research aims to give further detail on softwall mechanisms and fill this void of information.

2.4 SUMMARY

Through analysing literature on highwall designs, it was observed that theoretical design is consistent throughout many literature sources. Many identified the same key factors influencing highwall design and stability. The extensive literature on highwall and slope failures help identify stable and unstable areas within the Central Pit at Meandu. Furthermore, as the criteria of each failure method is consistent throughout the different literature sources, it assisted in categorising the geotechnical risks associated with highwalls. There were minimal gaps in the literature around highwalls which also directed the focus of this project to softwall design and implementation.

As previously emphasised, there is minimal information available in regards to the implementation and effectiveness of softwalls. It was observed that only case studies and theoretical assumptions were available. It was aimed that these gaps in literature were encapsulated in this report. By analysing effective implementation of softwalls at Meandu Mine, as well as their associated risks, a more detailed understanding of them is available. This will aid in future developments as well as mitigation plans. The case studies reviewed emphasised how the implementation of softwalls reduce the risk hazards as well as severely reducing the likelihood of failure occurring, without removing the risk completely.

The review of this material allowed for thorough understanding of highwall and softwall designs, risks and benefits to be gained. This information was then used to review the geology and geotechnical information to determine the applicability of softwalls at the mine.

3. Meandu Mine

3.1 Location

Meandu mine is located 200km North-West of Brisbane and mines coal within the Tarong Basin. The Basin trends North-North-West to South-South-East and is approximately 75km in length and 10km wide (Geoscience Australia, 2016). Figure 6 depicts the location of the Basin as well as its size relative to other basins located within Queensland. As illustrated, the Tarong basin is one of the smaller basins in South-East Queensland.

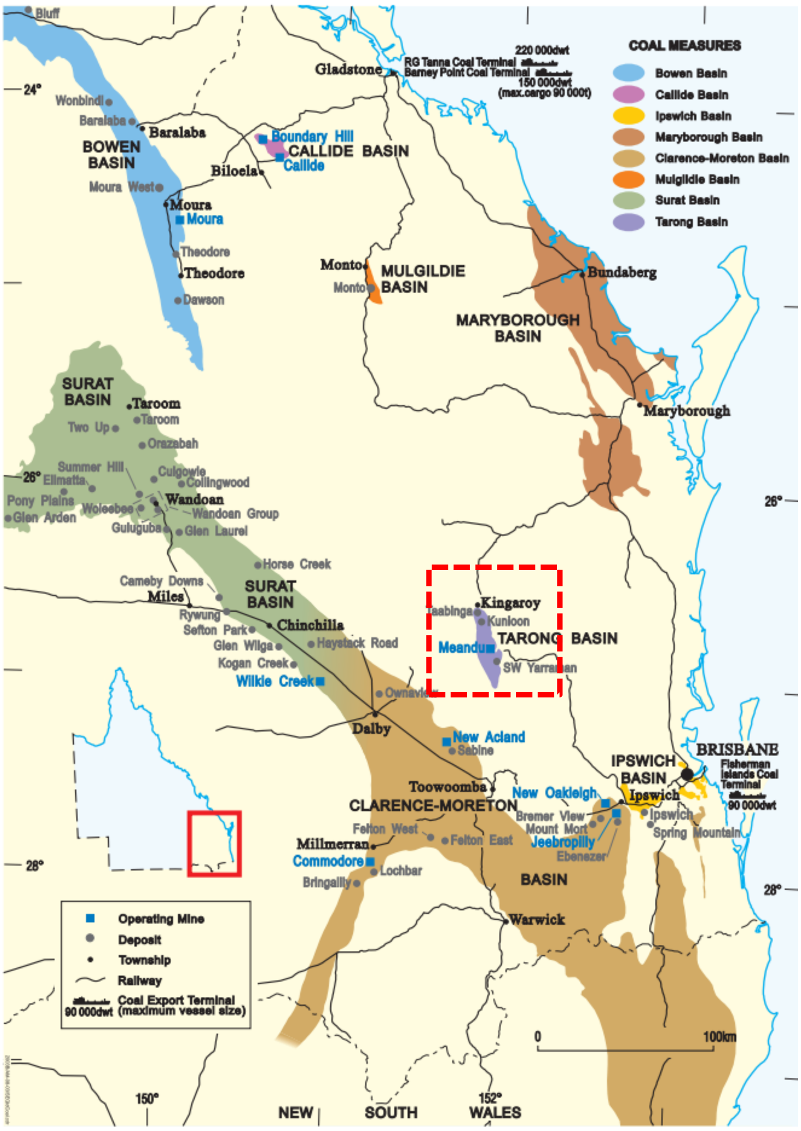


Figure 6. Location of the Tarong Basin and Meandu Mine (Mutton, 2003)

The Tarong Basin developed over the Devonian to Quaternary time period with the coal beds believed to be formed in the Late Triassic period (Simmons, Edwards and Ferdinands, 2013). It is thought that the material was deposited by braided streams, generally contains coarse-grained sediments (Simmons, Edwards and Ferdinands, 2013). The Tarong Basin is believed to have formed at a similar time to the Ipswich Basin located South-East of Meandu Mine (Geoscience Australia, 2016).

May of the faults in the area are North-South trending normal faults and also encompass grabens and shear zones which can be up to 20m in width. The faults and shear zones allow for large displacements to be observed. This may result in reverse faults or strike-slips if previous faults are reactivated (Simmons, Edwards and Ferdinands, 2013).

3.2 STRATIGRAPHY

The stratigraphy of the Tarong basin is illustrated in Figure 7, which highlights two major discontinuities present in the area. The Basin is also bound by faults which allowed for braided alluvial fan deposits to be formed (Simmons, Edwards and Ferdinands, 2013). This was due to the Stuart, Tanduringie and Cooya fans on the Western side of the Basin which corresponded to the location of the Stuart River and Tandurgingie and Cooya Creeks (Geoscience Australian, 2016). These systems ran to the east and were believed to be of *high energy* (Geoscience Australia, 2016), due to the large conglomerates present. Thus, the sediments within the basin vary in size from finer mudstones to coarse conglomerates (Geoscience Australia, 2016). Although, they are relatively sorted due to the deposition from the streams that were previously present (Mutton, 2003). The variety of materials present induce problems during mining as the strength and stability of each material changes. The changes in stratigraphy also changes the acceptable and suitable inter-ramp and overall slope angles.

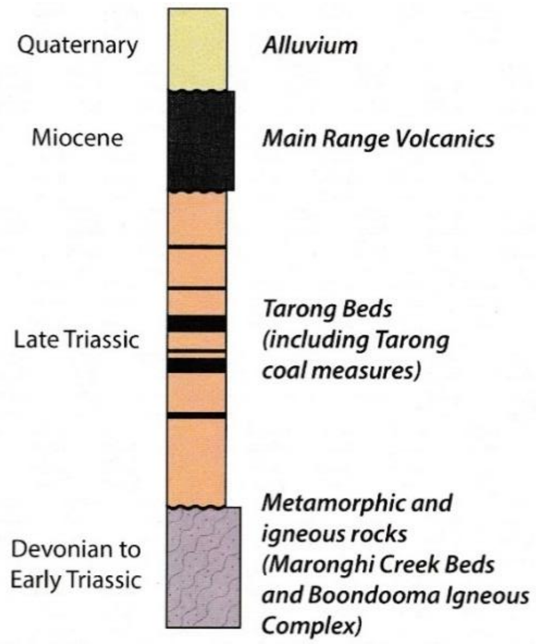


Figure 7. Stratigraphy of Tarong Basin (Simmons, Edwards and Ferdinands, 2013)

3.3 TARONG BASIN COAL

The Tarong Basin is host to a number of coal seams of varying thicknesses and qualities. The coal is believed to be deposited via braided stream deposits (Simmons, Edwards and Ferdinands, 2013) and have contain layers of fine quartz, clay or iron rich materials (Simmons, 2012).

As presented by Simmons (2012) the coal seams unconformably overlie Devonian-Carboniferous Maronghi Creek Beds on the eastern side of the basin and Later Permian-Triassic Boondooma Igneous Complexes on the western side (Simmons, Edwards and Ferdinands, 2013). Areas of the Tarong beds have experienced intrusion from younger portions of the deposit which is emphasised around the Nyora Clay pit (Geoscience Australia, 2016). Furthermore, thick basalt flows and weakly consolidated lithic sediments overlay the seams (Simmons, Edwards and Ferdinands, 2013). These overlying materials are of Jurassic and Cainozoic ages (Huleatt, 1991) and are similar to the deposits found in the Ipswich Basin (Geoscience Australia, 2016).

As stated by Pegrem (1995), the coal has subtle coking properties however is generally of steaming quality. While some coal is of high enough quality to be delivered straight to the power plant, due to the high ash content (Simmons, Edwards and Ferdinands, 2013) much of the coal requires processing before being delivered. The coal has low volatility and sulphur content but the ash content can be as high as 45% (Pegrem, 1995).

The coal generally requires to be blasted prior to excavation which results in the sub-vertical dig faces controlled by the jointing and cleating (Simmons, Edwards and Ferdinands, 2013). Offsetting of benches is also implemented when mining both fresh and weathered coal however, when Miocene materials are present, wider benches are used (Simmons, Edwards and Ferdinands, 2013).

3.4 MEANDU SEAMS

Within the Meandu mine, there are three major seams that are mined. The Ace seam is the uppermost seam which is separated into three plies. The Ace seam as an average thickness of 5.7m (JM Mining Services, 2015) and is commonly affected by weathering which occurred during the Tertiary period. The second seam present is the King seam which ranges in thickness from 2-20m (JM Mining Services, 2015). It is generally broken into three plies and a fourth thin ply is identified in the south-east of the mine.

Finally, the Queen seams are present below the King seam. There are nine seams present which are separated into Upper and Lower Queen. The Upper Queen comprises of seams A, B, C and D while the Lower is E, F, G, H and J. Each of the seams contains three plies and have a greater tendency to split (JM Mining Services, 2015).

While there are a number of seams below the Queen including; Prince, Baron, Duke and Duchess, their low quality and inconsistency, results in them being uneconomical to mine currently. As a result, the interburden under the Queen seam will not be analysed nor will these lower seams be presented in this report. The seam stratigraphy that will be studied in this report is outlined in Table 2.

Table 2.
Coal Seams and Plies

Group	*Seam*	*Ply*
		Ace 1
Ace	Ace	Ace 2
		Ace 3
		King 2
King	King	King 3
		King 4
		King 5
		A1
Upper Queen	A	A2
		A3
		B1
	B	B2
		B3
		C1
	C	C2
		C3
		D1
	D	D2
		D3
		E1
Lower Queen	E	E2
		E3
		F1
	F	F2
		F3
		G1
	G	G2
		G3
		H1
	H	H2
		H3
		J1
	J	J2
		J3

Source: JM Mining Services (2015)

3.5 HIGHWALL DESIGNS

As previously stated, the geology at Meandu changes dramatically, as does the strength of the materials. Thus, when designing pit shell, including highwall designs, the varying material properties need to be considered. Pits are designed for the reserve model generated through Vulcan, Deswik and Spry. From this model, pit designs are engineered from mining blocks which are generally 100m in length and can vary from 70m to 100m in width (Downer Mining, 2011). These dimensions are determined to optimise equipment productivity and maximise coal recovery. To further maximise efficiency of the equipment, 10m bench heights are maintained throughout the mine. However, as the depths and orientations of the coal vary between the pits, highwall and bench designs also vary.

In accordance to Downer's regulations the weakest material properties dictate the design of the highwalls. Table 3 summarises the maximum excavation parameters of the different materials. Due to the characteristics of some materials present, their parameters are specified on a case by case basis (Downer Mining, 2011). The outlined parameters were determined after inspections were completed by Sherwood Geotechnical and Research Services (Downer Mining, 2011), as well as the geotechnical advice and digital elevation model generated from Stanwell.

Table 3.
Excavated Slope Parameter Guidelines

Material	*Tertiary (general)*	*Fresh basalt Tertiary*	*Weathered Triassic – all rocks*	*Fresh Triassic Non-Coal rocks*	*Fresh Triassic Coal*
Max. Inter-Ramp Angle (Degrees)	37	70	45	70	N/A
Max. Bench Batter Angle (Degrees)	70	70	70	70	80
Max. Bench Height – Truck and Shovel (m)	10	45	10	45	N/A
Max. Bench Height – Dragline (m)	#	#	25	75	N/A
Min. Toe line Bench Width (m)	20	15	15	15	N/A

Source: Downer Mining (2011)

Figure 8 illustrates the expected highwall design for Central Pit and incorporates a minimum road width of 50m as well as berm widths of 5m. These road widths allow for a two-way roadway that accommodates the largest trucks on site, Hitachi EH500's. The Central Pit design illustrated is designed for the use of an excavator to the dragline horizon and it should be noted that the highwall design varies when designed for the dragline.

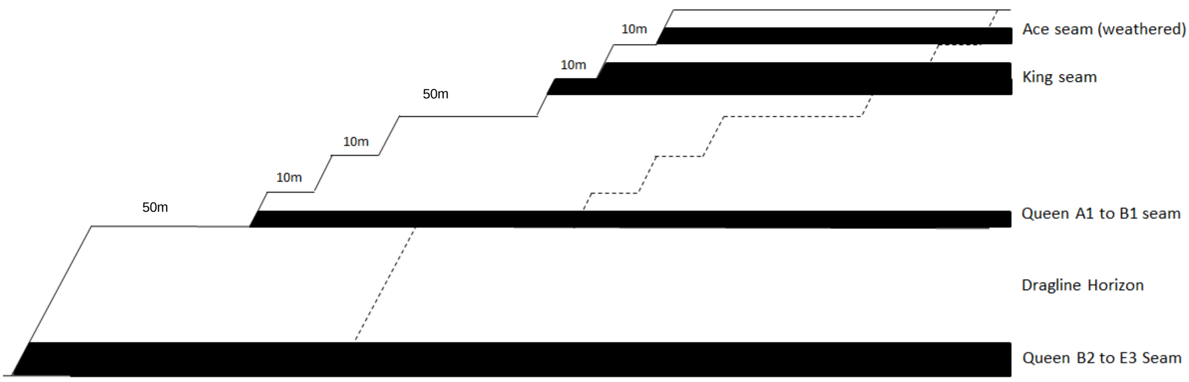


Figure 8. Central Pit Highwall Design (Downer Mining, 2011)

As Central Pit is currently mining the Queen seam, analysis will be conducted for the dragline. However, highwall production analysis will be completed for both the dragline and excavators and it may still be developed via excavator. Final analysis will compare the dragline hours and costs to ensure it is a fair comparison and the findings are relative.

3.6 Central Pit

Central Pit is the largest and deepest pit at Meandu and contains the thickest seams, making it a valuable extraction zone. As seen in Figure 9, there are a number of faults which run through Central Pit.

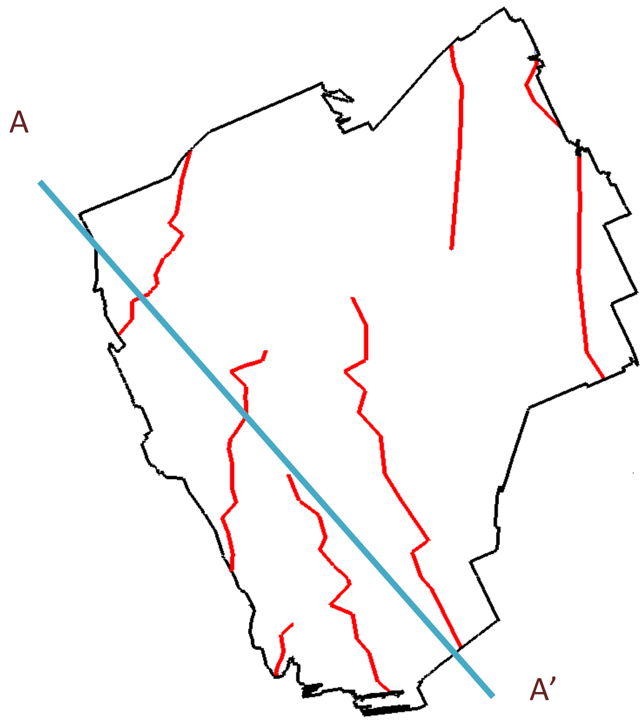


Figure 9. Faulting in Central Pit at Meandu

Central Pit maintains a 70° highwall for the Northern third of the pit with a 45° softwall for the remaining two-thirds of the wall. This is illustrated in Figure 10, with the distance of the softwall shown in blue and the highwall in orange. The implementation of the softwall is due to weak materials present as well as the numerous faults.

Figure 10. Presence of Highwall and Softwall in Central Pit

The softwall has been implemented to increase the stability of the highwall. By reducing the angle of the wall, the weight of the material pushing down to slide (and fail) is reduced, thus stabilising the wall. However, as the softwall has not been implemented for the entire length of the wall, the area where the wall changes from a highwall to a softwall generates an area of possible wedge failure. This will be discussed in detail in a later section.

The cross section in Figure 11 comes from the blue line illustrated on Figure 9. In this cross section, the faults and grabens of Central Pit are evident which emphasises the requirement for softwalls in the area. These displacements are shown against the geological model to emphasise their effect on the geology and different coal seams.

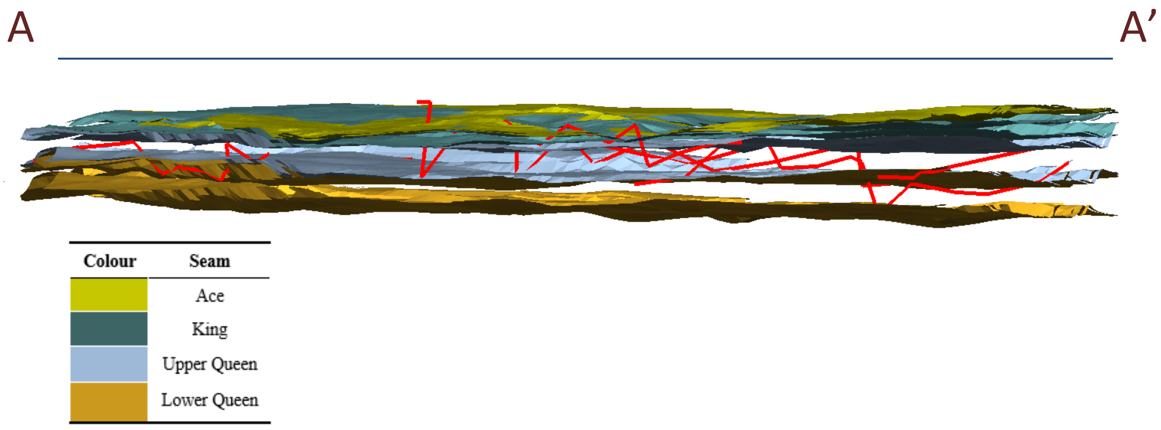


Figure 11. Cross Section of Central Pit

The Western side of the cross section is the current highwall, which has a softwall in place. The high number of faults in this area emphasise the requirement for a softwall to be implemented. The softwall is continually monitored by a Ground Probe monitoring radar that alerts of movements greater than specified distances. The Eastern side of the cross section identifies some faults however; they are deemed to be stable as they are excavated to a lower than usual angle. This is to accommodate ramp access into the pit. While it cannot be seen in the cross section presented in Figure 11, there are no major faults or discontinuities present in the Northern or Southern ends of Central Pit. From this, only the Western highwall of the pit will require a softwall.

4. ANALYSIS

4.1 GEOLOGICAL MODEL

4.1.1 Generation

The geological model is generated from data gathered from boreholes and surveys. Exploration at Meandu has occurred for 32 years during the different owners. The data is regularly updated through new drilling schemes with the borehole spacing based off geological, statistical and geostatical evaluations. The drill pattern generally occurs on a 60m x 60m spacing however, due to the conditions of the mine, it does not always adhere to this. This can generate inaccuracies in the model as the location of the seams and faults can vary.

The most recent drilling at Meandu occurred during August 2015 which focussed on Central Pit to further identify the extent and throw of the faults. The results of the data gathered directly impacts the geological model and the designs of the highwall and softwall. Before the data is imported into MineScape to generate the geological model, it is authenticated to ensure its accuracy and validity. During the validation process, data can be excluded for a number of reasons including;

- Incorrect survey data;
- Missing or incomplete geophysical logging;
- Drilling was abandoned before any useful intercepts were encountered; and
- Modelling purposes.

The most recent drilling data had 197 holes excluded resulting in the use of 5,511 holes, gathered over time, being deemed suitable for modelling both structure and quality. This validated data is then imported into MineScape to generate the geological model. As the geotechnical engineers at Meandu work with Vulcan software, the MineScape data is exported into a Vulcan format. JB Mining found the difference between these models to be 0.03%, thus deemed accurate for use by the engineers. The location of the boreholes used to generate the model are displayed in Figure 12.

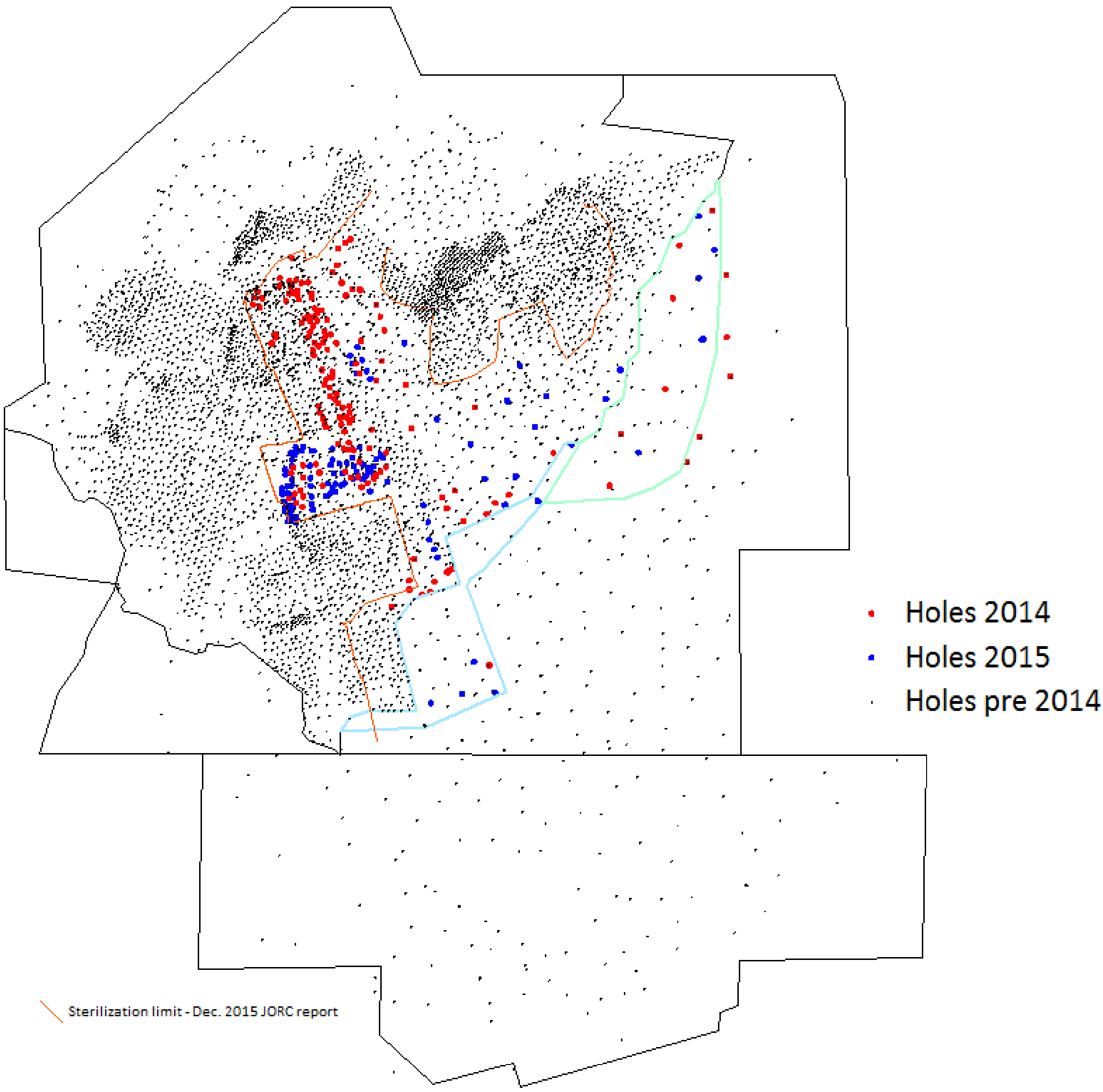


Figure 12. Borehole Locations (JB Mining, 2015)

4.1.2 Accuracy

According to the Geotechnical Engineers on site, there can be a variance in the location of the coal seam between boreholes. Additionally, there has been occurrences where the faults have been positioned 10-20m from their location on the model. These variations are due to unforeseen or unexpected changes or interactions within the lithology. Many of the faults on site terminate before passing through the entire site or deposit. As a result, any faults whose throw is 5-10m are not included in the model to mitigate the use of poor drilling resolution resulting in incomplete data on these large throws.

There are some discrepancies between the geological model and what is found when mining however, the geological model is constantly reviewed and updated. The analysis of the model aimed to quantify the difference which resulted in the determination of a flexibility zone around faults and seams. To do this, the geological model was overlayed by survey scans to allow for the location differences to be observed. It was found that if a flexibility zone of ±1.5m was implemented for the coal seams. This flexibility zone was determined for the entire mine and showed the area in which 95% of the faults fell. This flexibility zone was determined for each seam but not each ply due to their close proximity.

The next stage in the analysis was to determine a flexibility zone for the faults. By examining the predicted and actual data in the same manner as previously outlined, it was observed that the erratic nature of the faults results in location variation of up to 22m. Using a 95% interval as well, a flexibility zone of ±15m was determined.

Through analysing the accuracy of the geological model, it was found that while there are inaccuracies in the predicted locations of the seams and faults, it is of high accuracy overall. It should be noted that the inaccuracies found in the model are due the inconsistencies of nature not inability of the model generation.

4.2 MATERIAL PROPERTIES

The suitability of softwalls, or other mitigation options, is highly dependent on the material properties. This analysis was completed by examining core samples gathered by JB Mining who were unable to provide samples for testing. However, a detailed visual inspection of the samples was completed with the data made available for this thesis.

The data provided was for all boreholes shown in Figure 12. This data was then sorted via Eastings and Northings to determine which were relevant to Central Pit. It was then found that there was minimal information available on the boreholes in this area especially in regards to the material strengths.

To overcome this lack of data, extrapolation of known data was completed for each material type and its respective coal seam horizon. This allowed for changes between the different interburden to be identified. For each material and the relevant horizons, the data was weighted as a function of distance from Central Pit. This placed a high influence on the data that was closest to Central with little influence applied to data that was further away. By completing this extrapolation, the changes in material properties were observed throughout the mine, especially around Central Pit. This weighting was completed through formulas in Microsoft Excel to generate weightings based on locations and proximity.

By completing this process for the different materials to the different horizons, the data was then examined to find common properties for the materials irrespective of their horizon. The results for the materials present in Central Pit are summarised in Table 4.

Table 4.
Central Pit Material Properties

Material	*Strength*	*Description*
Stone	Moderately weak to considerably strong	Thin, banded, clayey grains
Carbonaceous Shale	Fragmented core sample	Friable, finely laminated, fissile, coal banded, interbedded
Coal	Very to moderately weak	Fine, clayey, mudstone, banded

These results show how the strength of the materials in Central Pit vary quite dramatically. The carbonaceous shale is so weak it was unable to produce core samples from drilling while the stone can be considerably strong. Additionally, the strength of the coal changes between the seams depending on the coal properties and degree of weathering. It was seen that the materials were weakest in areas of faulting.

Furthermore, other characteristics of the materials further added to the weakness seen in the area. The friability and lamination in the carbonaceous shale can result in material failure during excavation. As the strength of the stone changes quite dramatically and has an erratic presence throughout the mine, it has a strong impact on the overall stability of the highwall. It was found, that in areas where the stone was moderately weak, it was not abundantly present.

It was also seen that all the materials were banded to at least a moderate degree. Banding has the ability to generate planes of weakness due to changes in the material bonding. This can also occur between material layers where there are severe changes in material properties. These changes and impact the stability of the slope by the generation of weakness planes.

Overall, the properties of the materials in Central Pit are considerably weak which was determined through extrapolation of known material properties. No strength tests were conducted due to the inability to gather material samples but, it is believed that this should occur before altering the softwall angle or implementing another mitigation option.

4.3 RISKS OF HIGHWALLS AND SOFTWALLS

The general risks associated with highwalls are common amongst the majority of open pit mines. However, the geology and materials present impact the severity of the risks and the possible failure mechanisms. Risks associated with the highwalls at Meandu, specifically Central Pit, are generally associated to the complex geology present. Table 5 summarises the hazards that are associated with the two major stratigraphic zones present.

Table 5.
Hazards and Mitigation Options for Different Material Types

Stratigraphic Zone	*Hazard*	*Mitigation*
Tertiary Materials	Unfavourable dips Perched aquifers Faults and unfavourable joint orientations	Daily inspections Ground Probe monitoring system in place
Quaternary Alluvium	Possible slope failure	Daily inspections Implementation of softwalls

Source: Downer Mining (2011)

Majority of these risks have been identified and mitigation efforts have been implemented including the use of Ground Probe monitoring systems and softwalls. After identifying the risks associated with the different stratigraphic zones, the risks associated with highwalls and softwalls were investigated respectively. The details of the material properties previously identified aided in the determining of the risks. Table 6 identifies the ratings of different risks associated with highwalls and softwalls.

Table 6.
Risks associated with Highwalls and Softwalls

Risk	*Highwall*	*Softwall*
Wedge Failure	Critical	Moderate
Slump Failure	High	Moderate
Rock fall	Critical	Low
Movement cause by Blasting	Low	Moderate

These ratings were determined by identifying the likelihood and severity of each risk, similar to a standard risk assessment. Modelling of the slopes with the respective materials was not completed as the definitive rock properties was unknown. However, after ongoing discussions with the engineers and geologists on site, it was determined that a detailed conceptual analysis would be sufficient for the area.

After analysing the orientation of the joints and faults in the Central Pit highwall, it was determined that wedge and slump failures were critical and high risks respectively. The development of Central Pit aimed to occur in such a manner that the fault would run through the centre of the pit however, the changing joint sets proved to be problematic. It was seen that when the angle of the wall was reduced, the risk of wedge and slump failures both reduced to moderate. While the softwall does not completely remove the risk, it reduces the respective probability and severity.

The areas identified as possible areas of failure have been highlighted in Figure 13. Figure 13 illustrates the data obtained from the radar scanner which monitors the Central Pit softwall. The bottom image in Figure 13 illustrates the movement of the wall. The monitoring system is established in such a manner that if displacement or velocity exceeds 1mm/hour or 1mm/day, alarms are sound. However, due to the clayey properties of some of the materials present, during periods of heavy rain, the allowable displacement and velocity increases to 2mm/day.

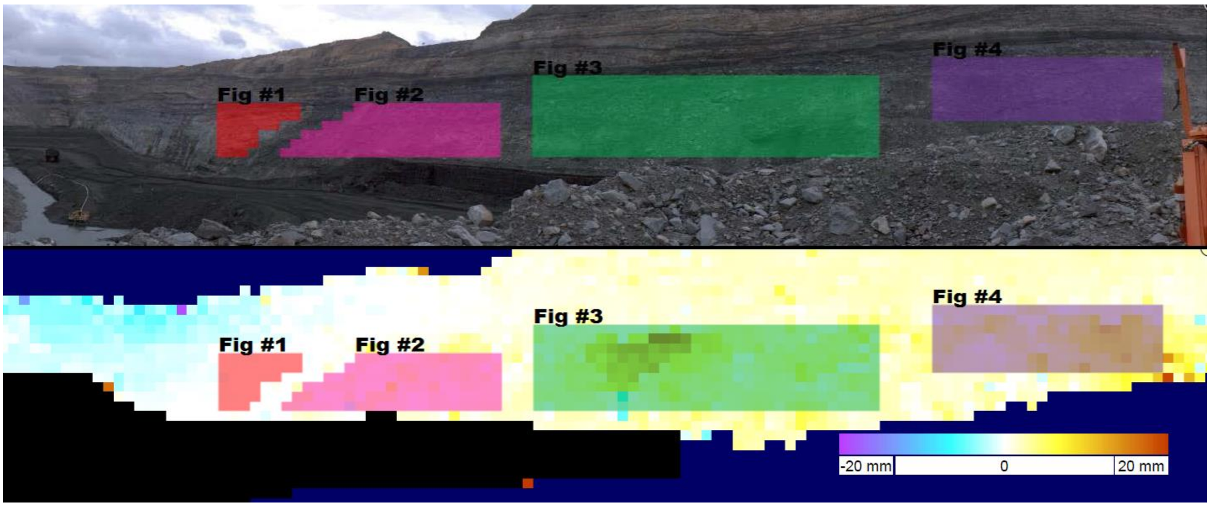


Figure 13. Monitoring Data of Central Pit Softwall (Downer Mining, 2016)

After examining the movement from the monitored data, it was then deduced that the area highlighted in red (Fig #1) had the potential of wedge failure occurring. This area is where the change from the highwall to softwall occurs and also contains jointing. This is a result of the increased opportunity for the jointing to daylight as a result in the change in angle. However, as seen in Figure 13, there is minimal movement occurring in this area.

The areas highlighted in pink, green and purple (Fig #2, Fig #3 and Fig #4) are areas which are most likely to experience slump failure. These areas were highlighted for potential slump failure due to the geological structures. With the presence of bedding planes, jointing and some faulting as well as the disturbance due to excavation, it develops an ideal environment for slumping. Additionally, during periods of high rain the weight of the material will increase and is likely to result in more material failing along the slip surface. This is due to an increase in weight of material which in turn increases the force motivating failure. However, while these areas were identified as areas where slump failure was most likely to occur, there have been no large failures observed. This is in comparison to previous failings that occurred before the implementation of the softwall.

Other risks associated with the highwall and softwall are rock fall and movement caused from blasting. The risk of rock fall went from critical to low after the implementation of the softwall. This is because the softwall is comprised of completely blasted material which reduces the amount of blocky areas. Furthermore, by reducing the angle of the slope, the material will require a greater weight and force to be able to fall. Finally, the risk of material movement as a result of blasting increased from a low to moderate risk after the softwall was developed. As previously stated, the softwall is comprised of completely blasted material, which is more prone to move due to vibrations than consolidated material. Thus, it resulted in the risk rating increasing. However, the risk is still at a reasonable and manageable level and can be controlled by monitoring blasting intensities when in close proximity to the softwall.

4.4 PRODUCTIVITY

Finding an average production rate of the four excavators on site, an hourly production rate of 1,810 BCM/hour was calculated. This was based on the excavation rates of the overburden on the King and Queen seams. To determine a relationship between the production hours required for each design, the amount of material was required. For this analysis, a 100m length was used with a wall height of 60m.

Using a 60m height and a 45° angle for the slope, it was determined that the width of the softwall was 60m, with calculation details displayed in Appendix A. From this, it was calculated that the volume of material required to be excavated was 180,000m^3.

By using the same methodology, the same parameters were determined for the standard highwall design. However, in these calculations, a consideration for benches and roads had to be taken. From this, it was found that the width of the highwall was only 21.83m. This is significantly less than a softwall which identifies that there will be a considerably less amount of material to be moved. By including four benches and a single road in the design, it was calculated that 110,514.6m^3 of dirt is required to be excavated.

From these volumes and the average productivity rates, an expected time of excavation can be calculated. The results from these analyses are displayed in Table 7.

Table 7.
Preliminary Productivity Analysis Results

Design	*Cross Sectional Area*	*Volume*	*Required Hours*
Softwall	1,800 m^2	180,000 m^3	99.5
Highwall	655.146 m^2	110,514.6 m^3	61

However, due to the nature of softwall, it is unable to be dug via excavators and can only be implemented via dragline. From this, the analysis was completed with the average dragline rates for Central Pit. A recalculation of the required volume of material to be moved was completed as the dragline does not incorporate benches as shown in Appendix B.

Using an average dragline productivity rate of 2,885BCM/hour, it was found that a softwall requires 274% more hours than a standard highwall design. Table 8 summarises the findings from the dragline productivity analysis. This analysis maintained the assumptions of height of 60m and length of 100m.

Table 8.
Dragline Productivity Analysis Results

Design	*Cross Sectional Area*	*Volume*	*Required Hours*
Softwall	1,800 m^2	180,000 m^3	62.39
Highwall	655.15 m^2	65,515 m^3	22.71

On top of this dramatic increase in working hours, the amount of rehandle also increase. As Central Pit is a tight area, the spoil piles need to stacked higher and further away. As a result of the increase in material moved, the percentage of material which is required to be moved further also increases. Thus, while there is such an intense increase in the amount of material to be moved in the slope development, as does the amount of rehandle. The exact percentages of rehandle can only be determined during production as it is highly dependent on the strip which is being mined. Thus, to complete the analysis and allow for the cost comparison to be completed, an assumption of 30% rehandle for a highwall and 45% for a softwall were employed. Using these assumed rehandle figures, the overall material movement was calculated with the results illustrated in Figure 14 (a) depicts the total amounts of material broken into prime and rehandle, while (b) exemplifies the split of the hours required.

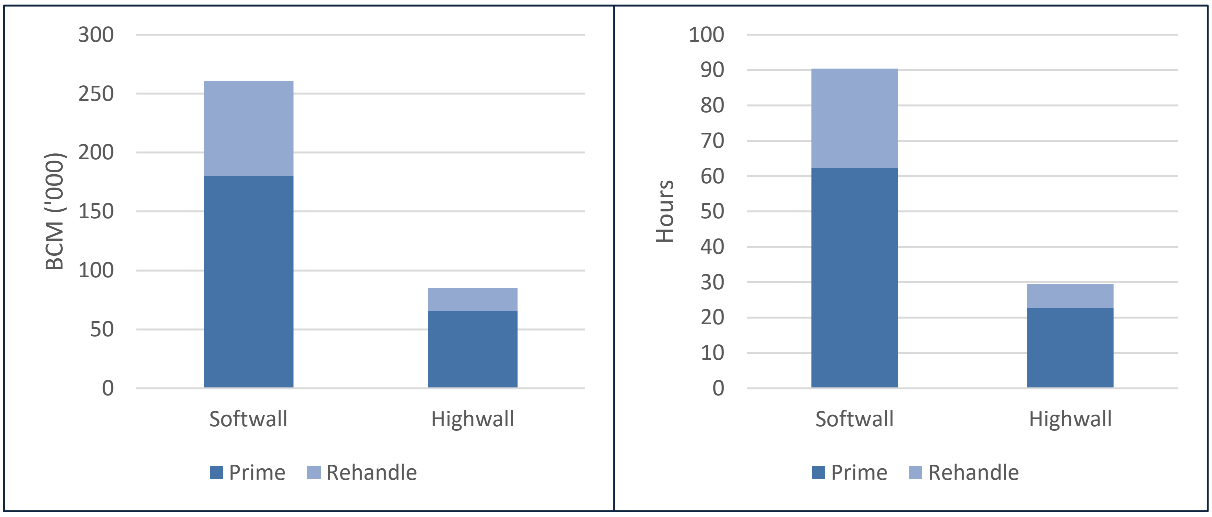
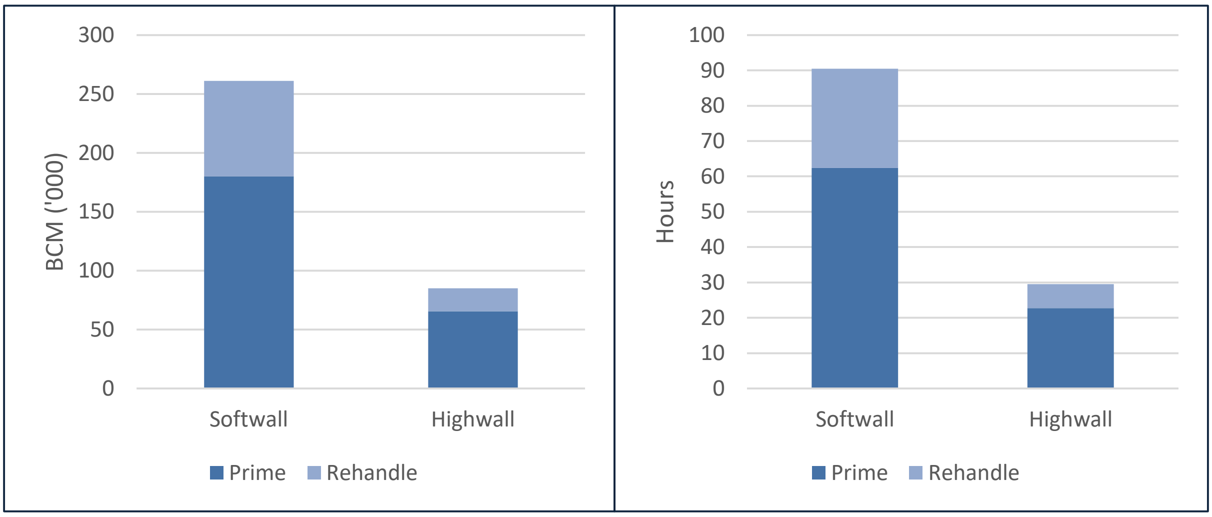


Figure 14. (a) Required Material Movement (b) Required Hours

Figure 14



clearly illustrates the increase in material movement and hours requited. It can also been see from these figures that a large portion of the increase in both material and time is due to the rehandle experienced. This has a strong impact on costs.

4.5 Cost

Exact costings have been withheld from this report for confidentiality reasons however indicative costs were implemented to illustrate the variance between the two designs. As Downer Mining is a contractor at Meandu, the cost of moving waste is detailed in the contract with Stanwell and has a number of factors that influence these costs. Again, due to confidentiality reasons, these details cannot be discussed. For this analysis the following assumptions were made;

- Cost to move material \$1/BCM;
- Cost to move rehandle \$1.25/BCM;
- Rehandle was only moved once;
- Operational costs were averaged to \$150/hour; and
- All costs are in Australian dollars and indicative only.

Using these indicative figures, the cost difference was found to be over \$200,000. The breakdown and differences are emphasised in Figure 15 where the costs are broken down into the different expenses.

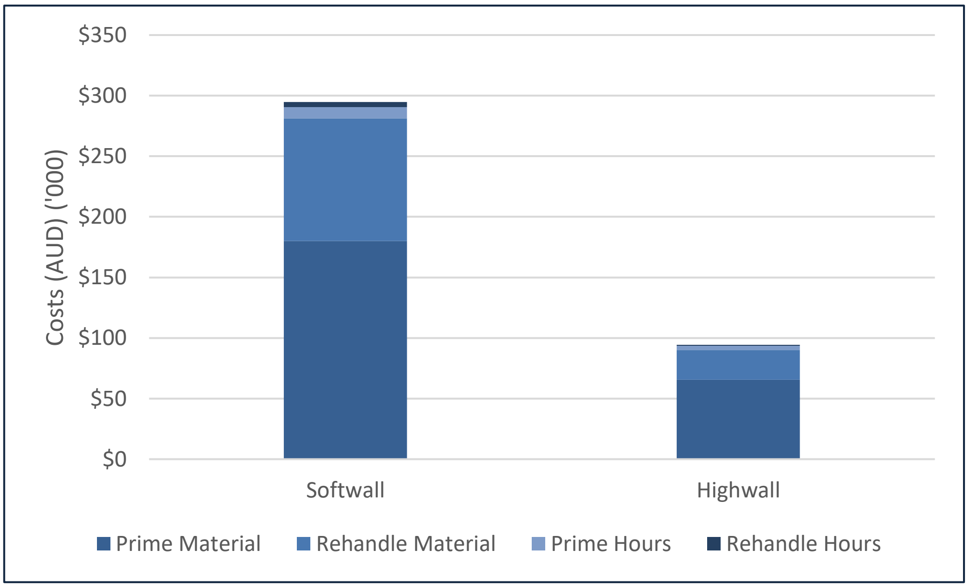


Figure 15. Cost Comparison

Figure 15 illustrates the dramatic increase of cost when a softwall is implemented. However, this does not include the cost of drill and blast. The amount of drilling required on a softwall is significantly more than that required for a highwall initially. A softwall does not require a pre-strip blast however, requires more and longer drilling. This is because, as seen in Figure 16, the blasted material is required to be the depth of the wall as well as the material, which will be moved. If the blasting does not extend this far, the effectiveness of the softwall is reduced.

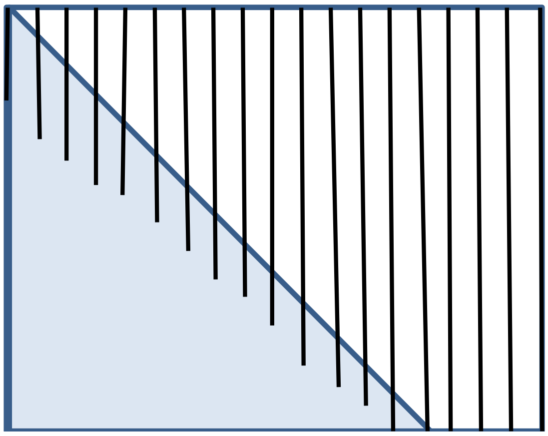


Figure 16. Indicative Drilling Depths for a Softwall

In comparison, a highwall requires a pre-spilt blast as well as continual blasting as coal extraction continues and the strips progress. Additionally, depending on the blast requirements, the cost of explosives can change. This results in ongoing drill and blast costs compared to the one off cost associated with a softwall.

The drilling pattern is dependent on the strip, depth and extraction method and the explosive used is determined from the material being blasted and the required result of the blast. These discrepancies in addition to the possible variance in the coal seam location, resulted in a drilling cost comparison not being completed. It was deemed that even if it were completed from the obtained results, it would not be accurate enough to represent the actual cost differences. Furthermore, as drill and blasting for the highwall is ongoing, the costs would fluctuate dramatically making the comparative results more inaccurate.

4.6 Other Mitigating Options

Other mitigation options could include the use of anchoring or reinforcing the slopes with mesh. Figure 17 illustrates an example of how anchoring can stabilise a slope. These systems work by passing stable structural features through the areas of weakness (Hayward Becker, 2015). While these stabilisation methods are applicable to final slope faces, they do not work for Central Pit as it is mined via strips.

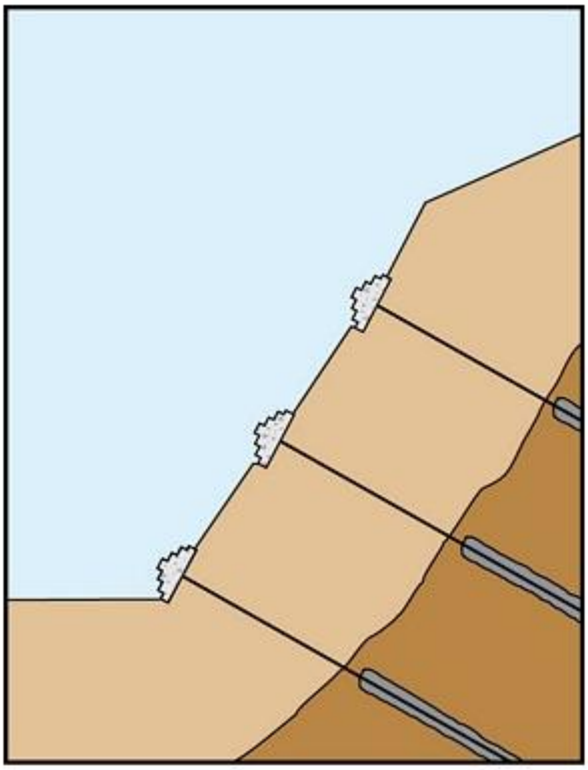


Figure 17. Slope Anchoring (Hayward Becker, 2015)

Non-permanent solutions can include the use of mesh reinforcements. The mesh overlay will aid in caching rock falls however, does not remove or lower the risks. The mesh is required to be supported at the top of the slope with optional additional supports through the slope (Geobrugg, 2016). The soft face of the mesh as opposed to the hard face of shotcrete allows the face of the slope to move but stops rocks falling during failure (Geobrugg, 2016). This is not deemed a suitable substitute for Central Pit due to the time required to implement the mesh supports. Additionally, the manner in which Central is mined means the mesh would be continually moved.

4.7 SUMMARY

By analysing how the geological model was generated the extent of the data that is included was observed. The accuracy of the model generated was found to be high and the model was deemed valid to be used for further analysis. However, discrepancies between the model predictions and actual locations of coal seams and faults were observed and by analysing these variations, a flexibility zone was determined around each coal seam and fault. This flexibility zone highlighted the area around the predicted location in which the seam or fault was likely to fall in 95% of the time. The flexibility zone for the seams was completed per seam as opposed to each ply due to their proximity. This resulted in a flexibility zone of ±1.5m. Through the same methodology, a flexibility zone for the faults was determined as ±15m.

To determine the materials in Central Pit and their strength, the obtained borehole sample data was examined. It was seen that the data obtained for Central Pit was minimal and resulted in data extrapolation being required. This was completed by highlighting data as a function of distance from Central Pit. This allowed the changes in the material properties throughout the mine to be observed, especially around Central Pit. This extrapolation was completed for each material type and the respective coal seam horizon. It was found that the strength of the materials was highly variable within the area and especially around faulting. This reinforced the assumptions that supported the softwall implementation.

These material properties were then used to determine the risks associated with both highwall and softwall implementation. The analysis determined that due to the unconsolidated nature of the materials as well as altering strength and consistency, the implementation of a softwall was ideal. The softwall also reduce the risk of wedge failure, slump failure and rock fall. This was due to the reduced angle generating a reduced force supporting failure as well as minimising the likelihood of discontinuities and jointing daylighting. These in turn, reduced the probability and severity of the aforementioned risks occurring. However, the risk of movement on the wall due to blasting was seen to increase. This is because the wall is comprised of blasted material. Even though the wall sits at an angle lower than the angle of repose for the different materials, some movement can still occur.

This movement is constantly monitored via GroundProbe radar monitoring system. This system alerts if deformation or velocity exceed 1mm/day. Through the monitored data an area of potential wedge failure was identified. This area occurs where the highwall changes to a softwall. Another three areas were identified to have the potential of slump failure due to the discontinuities and faults in the area. Overall, this monitoring is important to ensure the safety of workers in the area. This monitored data also allowed for the change in risks to be identified and deemed that the implementation of the softwall reduced the overall risk.

A productivity comparison was completed and it identified a major increase in material movement when a softwall is executed. This is because of the additional material that is requited to be moved. Furthermore, due to Central Pit having such a small area, the spoil is required to be stacked higher and further away to ensure there is sufficient room for working. This resulted in a higher percentage of rehandle being moved further away. Overall it was found that a softwall required more than 175,000 additional bank cubic meters to be moved under the assumed design assumptions. With rehandle amount increasing by over 61,000BCM. This additional movement required another 61hours of production.

Finally, it was found that the costs associated with the softwall were significantly larger than those associated with the highwall. The cost comparison did not include the drill and blast costs as it was deemed that this analysis could not be accurately completed from the gathered data. However, indicative figures illustrated a cost increase over 300% for a softwall.

By completing this analysis, it was determined that even with a significant increase in cost and a notice drop in productivity, the use of a softwall was deemed mandatory. Due to the generally weak materials and the number of faults, joints and discontinuities in Central Pit, the risk of maintaining a highwall outweighs the financial and time impacts.

By examining the applicability of other mitigation options it was found that without trialling the different mitigation options, it was deemed that implementing a softwall was the best option for Central Pit. The other mitigation options would require additional hours to removal and implementation as each strip is progressed. Due to the nature in which Central Pit is mined, a softwall is the safest option for the highwall. Even with the increase in costs and decrease in productivity, it is recommended that a softwall be maintained.

5. PROJECT MANAGEMENT

Due to the length and required detail of this project, a detailed schedule was required. By generating a Gantt Chart, highlighting critical tasks and identifying the resources required, it allowed for the project to be completed and generate significant and beneficial results. By identifying the reliance between the tasks, a critical path was identified, highlighting the critical tasks of the project. The completion dates set in the Gantt Chart allow sufficient time for the tasks and included leniency to allow for interruptions that occurred. These interruptions are outlined in the Risk Management.

5.1 PROJECT SCHEDULE

To ensure that the project is completed on time and with a high degree of accuracy and detail, a Gantt Chart was generated for all tasks and is presented in Figure 18. The schedule only indicates the allocated time periods.

A number of tasks were altered from the completion of the Literature Review. These tasks were altered to better align with the projected outcomes of the project. Additionally, due to some unforeseen restraints, some of the initial tasks were unable to be completed. Figure 18 illustrates the tasks that were initially outlined and does not include the changed tasks as these tasks were altered in accordance to the contingency plan.

5.2 CRITICAL TASKS

A critical task is a task whose completion determines the starting date of the following task. If a critical task is delayed, it has the potential to hinder the on time completion of the project. Thus, it was determined that a leniency of two days was applied to all critical tasks to ensure the completion of the project. In contrast, non-critical tasks can be completed at any time and do not depend on the completion of other tasks. However, their completion is a necessity for the completion of the project thus, they should be completed in a judicious manner.

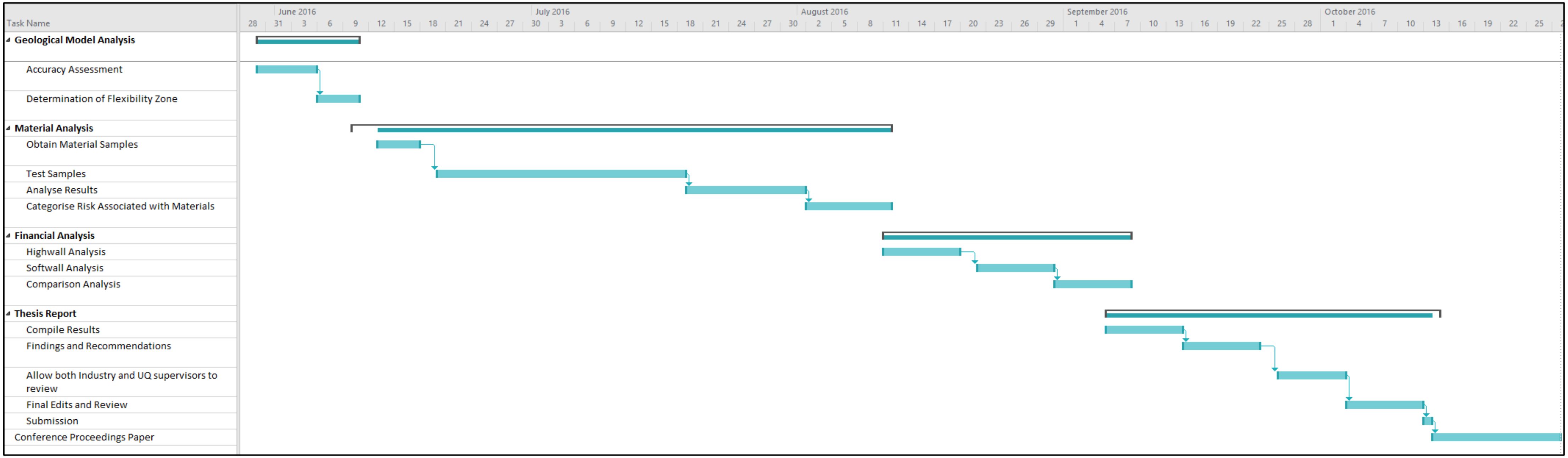


Figure 18. Project Gantt Chart

5.3 PROJECT REQUIREMENTS

To successfully complete this project, a number of resources are required. Table 9 identifies major tasks to be completed as well as the respective resources required and activities.

Table 9.
Task Resources and Activities

Task	*Resources*	*Activities*
Determination of Geological model flexibility zone	Geological model from site Vulcan software Survey scans of highwall progression	Determine the accuracy of the model Determine the flexibility zone
Analysis of material amounts and properties	The core sample data gathered by JB Mining The lithology dictionary	Determine critical properties of materials Determine amount of additional material to be moved
Categorisation of highwall risks	Analysis completed in this report	Categorise the risks based on the severity of their impact
Production Analysis	Production rates from site Data generated from this report	Determine the amount of material and production hours in a highwall Determine the amount of material and production hours in a softwall Compare results
Cost Analysis	Costs from site	Determine the cost of highwall Determine cost of softwall Compare results
Comparison of geotechnical risk, cost and current standards	Results from previous tasks	Categorise risks of softwall Compare production costs Identify relation to current mine standards and any recommendations

To ensure that the project was completed on time, all tasks and activities were completed by their respective completion dates. To ensure the consistent and accurate completion of these tasks, regular meetings with the supervisor occurred. Furthermore, constant communication with industry about project developments and findings were maintained in order to identify any outliers in the results.

6. RISK MANAGEMENT

To ensure the on time completion of this project, a risk assessment of all the potential physical and process hazards was completed. Potential hazards were identified and their likelihood and consequence established using Table 10.

Table 10.
Risk Assessment

Likelihood	*Consequence* *Minor*	*Medium*	*Serious*	*Major*	*Catastrophic*
Almost Certain	Moderate	High	Critical	Critical	Critical
Likely	Moderate	High	High	Critical	Critical
Possible	Low	Moderate	High	Critical	Critical
Unlikely	Low	Low	Moderate	High	Critical
Rare	Low	Low	Moderate	High	High

Source: Queensland Government (2010)

Table 11 defines the different levels of likelihood while Table 12 identifies the management responses to the different risk classes.

Table 11.
Description of Risk Likelihood

Likelihood	*Description*
Almost Certain	Recurring even during the lifetime of the project
Likely	Event that may occur frequently during the lifetime of the project
Possible	Event that may occur during the lifetime of the project
Unlikely	Event that is unlikely to occur during the lifetime of the project
Rare	Event that is highly unlikely to occur during the lifetime of the project

Source: Queensland Government (2010)

Table 12.
Respective Management Responses to Risk

Risk	*Management Response*
Low	Below the risk acceptance threshold and do not require active management. Some could require monitoring
Moderate	Lie on the risk acceptance threshold and require active monitoring. Implementation of additional measures could aid in further reducing the risk
High	Exceed the acceptance threshold and require proactive management. Includes those which action has been taken but further risk reduction is impractical however, requires a sign-off from senior management
Critical	Significantly exceed acceptance threshold and require immediate and urgent attention

Source: Queensland Government (2010)

Hazards affecting the completion of the project, were identified as well as their likelihood and consequence. From this, their risk was assessed and management response identified. Thus, the hazard was reassessed with the management response to observe the risk to the project and the results are displayed in Table 13.

Table 13.
Potential Project Hazards Risk Assessment

Hazard	*Likelihood*	*Consequence*	*Risk*	*Mitigation Plan*	*Reassessed Risk*
University Interferences	Almost certain	Medium	High	Time management planning	Moderate
Non-University Interferences	Possible	Medium	Moderate	Time management planning	Low
Failure of the course	Unlikely	Major	High	Regular contact with supervisor	Moderate
Technology Failure	Possible	Major	Critical	Backup all work in a number of places	Moderate
Failure to recognise data trends	Unlikely	Major	High	Seek assistance and advice when required	Moderate
Failure to gather data from Industry	Unlikely	Major	High	Use other contacts available to retrieve data	Moderate

6.1 CONTINGENCY PLAN

While mitigation plans were outlined for the potential risks identified, a contingency plan was developed to in the event the mitigation efforts are inadequate. Fortunately, only one part of the contingency plan was required. Due to being unable to collect soil samples to test for strength and other properties, data had to be obtained through pre-existing databases as previously mentioned. All other plans for the project were successful and the other contingency plans were not required.

7. CONCLUSION AND RECOMMENDATIONS

It is observed that due to Central Pit being mined via strips, the implementation of a softwall is the optimal solution to the problems observed. The weak materials present issues during excavation due to their friability which also result in their instability at high angles. Thus, the implementation of a softwall reduces the force on the slope which motivate failure. The methodology used in this project, while focussed on Central Pit, can be used to analyse other pits at Meandu. Furthermore, this methodology can be used to indicate the applicability of softwalls at other sites.

Recommendations for future investigations start in the determination of the flexibility zone. If the analysis was focussed on Central Pit solely, a more accurate zone could be determined. If this was completed for each pit individually, patterns would become more prominent and predictions could become more accurate. While it is thought that all previous strips should be analysed, due to the addition of more data to the model over time, the accuracy of the model should have also increased over time. Thus, making the findings from the previous strips and their models, inaccurate.

Further recommendations include gathering soil samples to be able to gather quantitative strength parameters. By obtaining the actual strength of each material present, modelling of the slope can be completed to determine a maximum angle for the softwall. This will allow for productivity and recovery to be maximised while minimising costs.

By adding these recommendations into a future study, the results obtained will be more accurate and better represent the conditions of Central Pit. These findings alongside the findings in this study would details and findings for Central Pit only and allow for more specific assumptions to be made. Additionally, by obtaining soil samples, it would allow the possibility of softwall implementation in other pits to be further explored. This could be significant when faults reappear in pits.

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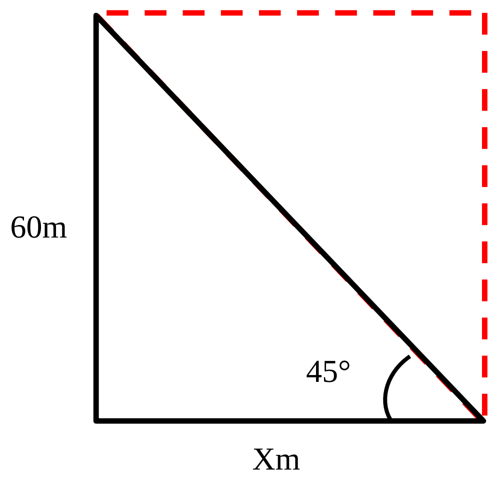
9. Appendix

9.1 Appendix A

Softwall productivity calculations

Width of softwall



$$X = \frac{60m}{\tan(45)} = 60\ m$$

Cross sectional area

$$\frac{60m\ \times 60m}{2} = 1{,}800m^2$$

Volume of softwall

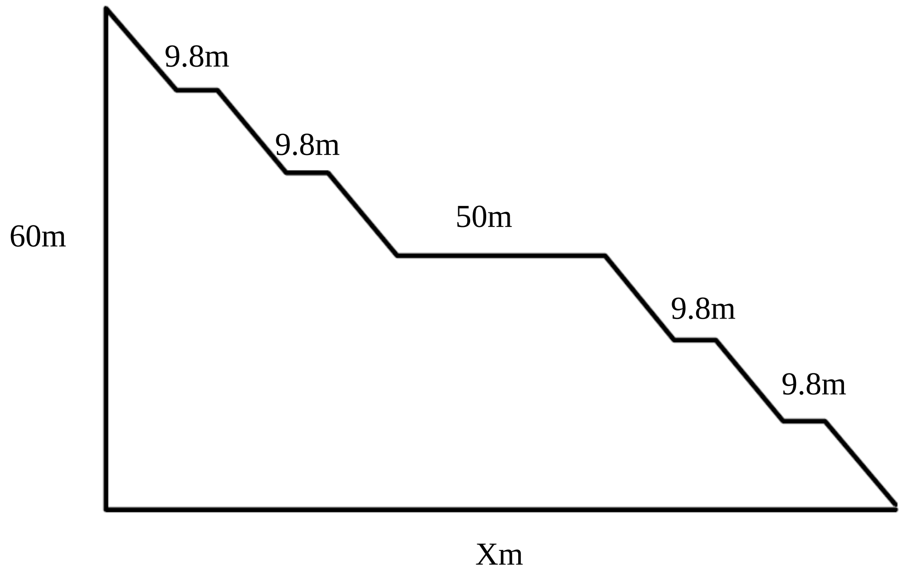
$$1{,}800\ \times 100 = 180{,}000m^3$$

Productivity

$$\frac{180{,}000m^3}{1{,}810\ \frac{m^3}{hour}} = 99.45\ hours$$

Highwall productivity calculations

Width of highwall with inter-bench angle of 70°



$$X = \frac{60m}{\tan(37)} = 79.62\ m$$

Cross sectional area

$$\frac{60m \ \times 79.62m}{2} = 1{,}105.146m^2$$

Volume of highwall

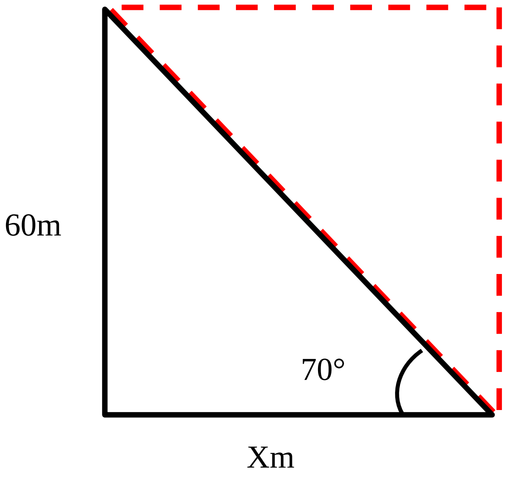
$$1{,}105.146 \ \times 100 = 110{,}514.6\ m^3$$

Productivity

$$\frac{110{,}514.6m^3}{1{,}810\ \frac{m^3}{hour}} = 61.06\ hours$$

9.2 APPENDIX B

Highwall productivity calculations for dragline



$$X = \frac{60m}{\tan(70)} = 21.84\ m$$

Cross sectional area

$$\frac{60m\ \times 21.84m}{2} = 655.15m^2$$

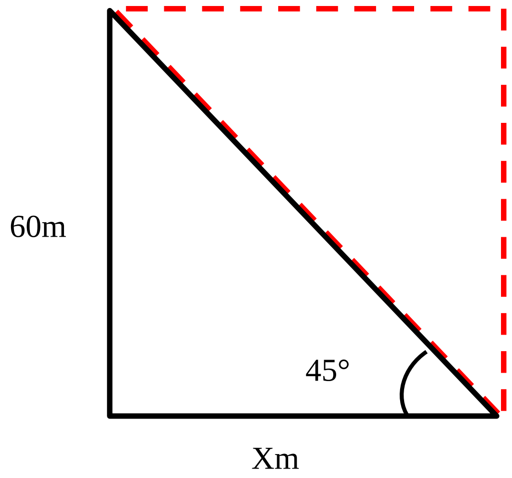
Volume of highwall

$$655.15 \times 100 = 65{,}515m^3$$

Productivity

$$\frac{65{,}515m^3}{2{,}885\ \frac{m^3}{hour}} = 22.71\ hours$$

Softwall productivity calculations for dragline



$$X = \frac{60m}{\tan(45)} = 60\ m$$

Cross sectional area

$$\frac{60m\ \times 60m}{2} = 1{,}800m^2$$

Volume of softwall

$$1{,}800 \times 100 = 180{,}000m^3$$

Productivity

$$\frac{180{,}000m^3}{2{,}885\ \frac{m^3}{hour}} = 62.39\ hours$$